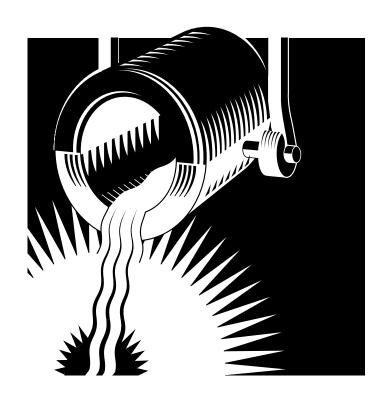
# METAL CASTING



# INDUSTRY OF THE **F**UTURE

Industry and government join forces for industrial competitiveness and a clean environment

# Geographic Distribution of U.S. Foundries









101 - 2

1 - 99

No metal casting foundries

The American metal casting industry was established in 1642. Today's metal casting industry employs over 250,000 in 3,100 foundries located in 49 states. The industry is dominated by small businesses: 80 percent of these foundries employ fewer than 100 people each.

The metal casting industry ships about 13 million tons of castings annually in excess of \$23 billion. Major end-use markets for metal castings include the automotive, pipe, industrial machinery, transportation equipment, and aerospace markets.

## COLLABORATION RESEARCH AND DEVELOPMENT FOR A MORE COMPETITIVE INDUSTRY

The U.S. metal casting industry is currently emerging from two decades of consolidation. Environmental and occupational regulations -- coupled with spiraling global competition -- have caused the demise of more than 2,000 metal casting companies over that period.

What remains today is a leaner, smarter, and more competitive industry, one that is a critical component of the nation's manufacturing base and an important contributor to its economic vitality. Casting processes are central to the manufacture of products as diverse as artificial heart valves and propellers for aircraft carriers. Cast metal products offer advantages unavailable from products made by other metal forming and fabricating techniques, such as intricate patterns and complex internal spaces. The industry's future is based on these advantages.

But the metal casting industry requires long-term, carefully targeted research and development to improve casting quality, increase productivity, and lower costs, while simultaneously improving energy efficiency and environmental performance.

An industry/government partnership -- the Metal Casting Industry of the Future -- is accelerating the development and use of critical new technologies. The Department of Energy's Office of Industrial Technologies (within the Office of Energy Efficiency and Renewable Energy) and the metal casting industry are working together to provide coordinated government support of R&D areas identified as high priority by the industry.

By considering the many points of view of this diverse industry, the Metal Casting Industry of the Future approach improves exchange of information and helps identify and solve problems. Coordinated planning helps eliminate duplication and gaps in R&D activities. As a result, cycle time from technological concept to application in the foundry is being reduced.

#### DEVELOPING A UNIFIED VISION FOR THE METAL CASTING INDUSTRY

A team of industry and association leaders has developed a focused and unified vision of the metal casting industry that describes how it will look in the year 2000 and beyond. Their vision document, *Beyond 2000: A Vision for the American Metal Casting Industry*, commits the industry to being the preferred supplier of net- or near-net-shape metal components. Its globally competitive products will be produced in an efficient, environmentally friendly manner. The industry's products will be viewed as necessary "engineered components" rather than as "commodities".

This Vision will be achieved through ongoing collaborations between the industry and its partners. DOE will continue to align Federal funds and coordinate across Federal agencies to support those projects that promote energy efficiency and environmental performance as well as product competitiveness. The vision continues to undergo industry-wide review to build consensus and to provide the basis for shaping a slate of near-, medium-, and long-term R&D opportunities for the industry.

Participants believe partnerships with government agencies, supplier companies, professional societies, and academia will be the cornerstone of the industry's future competitiveness and technical sophistication.

#### FACING KEY INDUSTRY ISSUES

To achieve its vision, the metal casting industry must overcome obstacles. In addition to its significant technological challenges, the industry faces key competitive, regulatory, and personnel hurdles:

#### Increasing Foreign Competition

The United States was traditionally the source of the world's best foundry equipment and technology. In the mid-1970s, however, the strong U.S. dollar created a competitive disadvantage for U.S. equipment suppliers, and encouraged imports of metal casting machinery.

#### REGULATORY ISSUES

Environmental and safety regulations consume more than 25 percent of new capital investment and account for up to 5 percent of production costs. The increasing cost of compliance is a driving force for technology enhancements. Designing systems and processes that go beyond compliance to reflect a resource productivity approach is a major strategy for improving industry competitiveness.

### • LIMITED AVAILABILITY OF TRAINED PERSONNEL

Depressed market conditions in the 1980s led to early retirements, staff reductions, and low levels of hiring. The result in the 1990s is a shortage of experienced, knowledgeable metal casting personnel.

As the industry faces these challenges with fewer, less technically educated personnel, the role of the metal casting supplier will become increasingly important. Metal casters and their suppliers will need to work together to develop the technology, equipment, and materials that will reduce production costs and improve casting quality.

### T H E V I S I O N

The U.S. Metal Casting Industry of the Future will be:

- The preferred supplier of engineered, netshape metal components
- Globally competitive
- Environmentally responsible
- Well capitalized and profitable
- A source of challenging and well-paying careers
- The world's benchmark for technology and innovation
- Supportive of a strong supplier base

#### STRATEGIES:

- Market and casting application development
   Increase market development activities to improve share in current markets by 10%, recapture 25-50% of lost markets, and increase the rate of new market development.
- Materials technologies
   Develop materials technologies to improve the variety, integrity, and performance of cast metal products.
- Manufacturing technologies
   Develop advanced technologies to increase productivity 15%, reduce average lead times 50%, and reduce energy consumption 3-5%.
- Environmental technologies
   Achieve 100% pre- and post-consumer recycling,
   75% beneficial reuse of foundry by-products, and the complete elimination of waste streams.
- Human resources, education, and training
   Attract significant talent to the industry, and keep present employees current with the latest technologies.
- Industry health and profitability
   Use health and profitability to increase funding for research, educational, and marketing programs by 10%.
- Partnerships and collaborations
   Combine the experience, resources, and knowledge available in public and private sector organizations.

#### ALIGNING INDUSTRY AND GOVERNMENT RESEARCH AND DEVELOPMENT OBJECTIVES

The Industry of the Future strategy aligns government funds to support those research and development projects that will result in a more energy-efficient and environmentally sound metal casting industry. The industry's vision identifies the following high-priority research and development needs:

#### • MARKET DEVELOPMENT

As emerging technologies are proven on the shop floor, industry's improved capabilities need to be aggressively marketed to customers. Key research priorities include:

- Improved lost foam casting technology.
- Definition of the advantages of semi-solid and squeeze casting technologies.
- New casting alloys.
- Casting metal matrix composites.
- Improved control and interaction of process variables.

#### • MATERIALS TECHNOLOGIES

The industry will help keep its products competitive by conducting applied research on the composition and thermomechanical behavior of the metals it casts, including:

- Improved dimensional control of castings.
- Elimination of casting defects.
- Clean cast metal technology to improve product integrity.
- Casting thinner walls to yield lighter components.
- Identification/standardization of cast metal properties.
- New casting alloys.

#### Manufacturing Technologies

The full potential of new manufacturing technologies will be realized by research in:

- Control/interaction of process variables.
- Breakthroughs in affordable automated equipment.

- Automated finishing equipment (robots) to decrease labor content, speed the process, and improve worker safety.
- Improved core removal methods to streamline production.
- Extended diecasting die life.
- Compressed lead time to get products to market faster.

#### • ENERGY EFFICIENCY

U.S. metal casters consume about 250 trillion Btus of energy per year. The research activities below will help to ensure continued supply of reasonably priced energy:

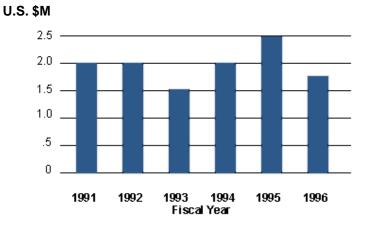
- Waste water recovery and reuse.
- Cupola furnace modeling and control using neural networks.
- Advanced sensors and process controls.
- Melting and holding furnace optimization.

#### • ENVIRONMENTAL TECHNOLOGIES

The industry will find ways to enhance the cleanliness of its processes, increase both pre- and post-consumer recycling, and explore ways to reduce, and eventually eliminate, waste streams through research and development activities including:

- Full characterization of waste streams.
- Advanced waste treatment technologies.
- Environmentally benign sand binders and additives.
- Improved methods of sand reclamation
- Beneficial reuse of solid waste products.
- Alternative processes or materials for reduced waste generation.

### FUNDING SUPPORT FOR METAL CASTING RESEARCH & DEVELOPMENT THROUGH DOE'S OFFICE OF INDUSTRIAL TECHNOLOGIES



Since 1991, DOE's Office of Industrial Technologies has supported research and development projects to enhance the energy efficiency and environmental performance of the metal casting industry. This commitment will continue through the Metal Casting Industry of the Future Process.

#### PARTNERING TO MEET TECHNOLOGY CHALLENGES

DOE is already partnering with the metal casting industry to facilitate technology developments in several of the targeted areas. The table on the following pages shows current research and development projects that are jointly supported by the metal casting industry and the DOE's Office of Industrial Technologies. At present, more than 135 U.S. metal casting companies are participating in DOE-supported research and development projects.

## RESEARCH SITES FOR CURRENT DOE-SUPPORTED PROJECTS IN THE METAL CASTING INDUSTRY



DOE- supported metal casting projects are now in progress at 20 research sites across the country and in Canada. The transfer of results on the foundry floor is a key goal of every research project. Already the projects are enabling some metal casting companies to increase energy efficiency, reduce energy use, reduce scrap, increase die life, and reduce production costs.

- 1. Albany Research Center (Oregon)
- 2. Canadian Materials Technology Laboratory (Ontario)
- 3. Carnegie Mellon University (Pennsylvania)
- 4. Case Western Reserve University (Ohio)
- 5. Climax Research Center (Michigan)
- 6. Florida A&M University
- 7. Idaho National Engineering Laboratory
- 8. Idaho State University
- 9. Iowa State University
- 10. L.E. Griffith & Associates (Illinois)
- 11. Materials Properties Council (New York)
- 12. Ohio State University
- 13. Pennsylvania State University
- 14. University of Alabama Birmingham
- 15. University of Alabama Tuscaloosa
- 16. University of Missouri Rolla
- 17. University of Northern Iowa
- 18. University of Tennessee
- 19. University of Wisconsin Milwaukee
- 20. Worcester Polytechnic Institute (Massachusetts)

#### Success Story: Matrix Technologies Commercializes Air Gauge System

One recent success of the Metal Casting Industry program is the non-contact Air Gauging System (AGS) developed by Matrix Technologies of Muncie, Indiana. Through critical support from OIT and a consortia of industry, the AGS was tested and validated by the Lost Foam Technology Research Laboratory at the University of Alabama -Birmingham. This enabled Matrix Technologies to bring to market the AGS within 18 months of product conception -- far sooner than original expectations. Brian Ginnard. President of Matrix. stated that the success of AGS can be directly attributed to Metal Casting Industry of the Future program support through the Lost Foam Technology Laboratory. The ability to commercialize the system so quickly would not have been possible otherwise.

The Matrix AGS provides a method of dimensional analysis that validates pattern dimensions and certifies overall part qualifications. It is a precise non-destructive, non-contact system allowing measurements of sand cores, EPC foam patterns, metal castings and other manufactured parts made from standard, exotic or low modulus materials.

PROJECT	OBJECTIVE	PARTNERS		
Research Site: Albany Research Center		Illinois Steel Founders' Society of America (Des Plaines)		
Energy Savings in Melting	Investigate ways to reduce energy use and cost in melting	Oregon Albany Research Center (Albany)		
Research Site: Canadian Materials Technology Lab		Illinois Wisconsin Aurora Industries, Inc. (Montgomery) Starline Manufacturing Co., Inc. (Milwaukee)		
Design Parameters for Lead-Free Copper-Based Alloys in Permanent Molds Process Parameters for Lead-Free Copper Based Engineering Alloys in Permanent Molds	Identify mechanical and physical properties, wear resistance, and corrosion behavior of permanent mold cast copper-base alloys Evaluate mold materials, improvements in casting fluidity, and grain refinement  Identify the effects of one, two, and	H. Kramer & Co. (Chicago)  Missouri AB Chance (Centralia)  Ohio Bunting Bearing Corp. (Perrysburg Brost Foundry Co. (Brecksville)  Pennsylvania Colonial Metals Co. (Columbia)		Statille Maridiacturing Co., Inc. (Milwaukee)
Impurity Limits in Aluminum Bronzes	three interacting impurities on aluminum bronzes	, ,		
Research Site: Carnegie Characterization of and Procedures to Eliminate Macro-Inclusions during Foundry Processing	Mellon University     Develop a non-metallic inclusions atlas and standards to evaluate the cleanliness of steel castings	Illinois Process Metallurgy International, Ir Taussig (Skokie)  Michigan Eagle Alloy (Muskegon)	nc. (Arlington Heights)	Pennsylvania Minteq Intl., Inc. (Easton) Wisconsin NUPRO Corp. (New Berlin)
	estern Reserve University	California	<b>.</b>	Crown Equipment Corp. (New Brennan) DCD Technologies (Cleveland)
Determination of Residual Stress and Softening Effects on the Life of Die Casting Dies	•Evaluate measurement methods and develop ways of reducing loss in die life caused by softening of steel and build-up of residual steel	Alloy Tool Steel (Santa Fe Springs)  Illinois  North American Die Casting Assoc FPM Heat Treating (Elk Grove)		Doehler-Jarvis Partnership(Toledo) ITT Automotive (Solon) Lindberg (Solon) Universal (Cleveland)
Effect of Composition and Processing on Thermal Fatigue Resistance of High Performance Die Steels	To improve the average life of a die-casting die  *To improve the average life of a die-casting die	Indiana CMI Tech Center(Bristol)  Michigan Chem-Trend (Howell) Briggs & Stratton Corp. (Ravenna) Ohio		Pennsylvania Latrobe Steel Co. (Latrobe)  Tennessee Harvard Industries (Ripley)  Wisconsin Badger Metals Tech. (Menumee Falls)
Research Site: Climax F	Research Services	Basic Aluminum Castings (Clevelar	nd)	Ohio
Effect of Late Stream Inoculation on Mechanical Properties of Pearlitic Ductile Iron	•Determine if ferroalloys reduce fatigue strength, impact toughness, and machinability	Q.I.T. America (Chicago) Wagner Castings Co. (Decatur)  Michigan  Briggs & Stratton Corp. (Ravenna)		Hickman Williams (Lakewood)  Wisconsin Waupaca Foundry, Inc. (Waupaca)
	ate University/Idaho National	Idaho Idaho National Engineering Labora	tory (Idaho Falls)	Michigan General Motors Research Center (Warren) GM Powertrain (Saginaw)
Intelligent Control of the Cupola Furnace	Develop a controller for the Cupola process	Illinois American Foundrymen's Society (Dindiana Dalton Foundry (Warsaw)	Des Plaines)	Oregon Albany Research Center, DOE (Albany)  Wisconsin Modern Equipment (Port Washington) Waupaca Foundry (Waupaca)
Research Site: Universi		California Pacific Steel Casting (Berkeley) American Steel Foundry (Alliance) Flow Technology (Cincinnati) Illinois Sawbrook Steel Castings (Cincinnati)		American Steel Foundry (Alliance)
Unconventional Methods for Yield Improvement through Directional Solidification in Steel Castings	Develop solidification software to simulate imposed thermal gradients and evaluate their effect on yield	American Steel Foundries (Granite NACO Technologies (Lombard) National Castings (Cicero/Melrose	• /	Pennsylvania Effort Foundry (Bath)
		Indiana American Steel Foundries (Indiana Harbor) Harrison Steel Castings (Attica)		Texas National Castings (Richmond) Southwest Steel (Longview) Texas Steel Co. (Ft. Worth)
		Iowa National Castings (Keokuk)  Kansas Atchison Casting Corp. (Atchison)		Wisconsin FALK Corporation (Milwaukee) Grede Foundries (Milwaukee) Patter Casted (Milwaukee)
				Pelton Casteel (Milwaukee) Stainless Foundry & Engineering (Milwaukee)
Research Site: L.E. Grif Foundry Energy Assessment	fith Associates  •Develop an energy manual for die casters	Illinois		Wisconsin Stroh Die Casting (Milwaukee)
Research Site: Materials		Alabama Southern Alloy (Sylacauga)	Massachusetts Wollaston Alloy (Braintree)	Texas KO Steel (San Antonio)
Development of Database Design Rules for Cast, High Alloy Steel Components	Develop design data, screening tests, and an atlas of micrographs	Indiana Ultra-Cast (Peru) Iowa	Ohio Manoir Industries (Elyria)  Pennsylvania	Wisconsin Stainless Foundry & Engineering (Milwaukee) Wisconsin Centrifugal (Waukesha)
		Keokuk Steel (Keokuk)	Duraloy (Scottdale)	

Research Site: Ohio St	ate University	Illinois Ingersoll Cutting Tool Co. (Rockford)	North Carolina Kennametal, Inc. (Raliegh)
High Speed Milling and Pulsed ECM	•Develop guidelines for machining H- 13 by high speed milling	North American Die Casting Association (Rosemont) Spartan Light Metal Products (Sparta) Thyssen Specialty Steel (Carol Stream)	Ohio DCD Technologies (Cleveland) GE Superabrasives (Worthington)
Assessment of Fast Shot Transition Point on Filling Patterns /Casting Quality for Pressure Die Casting	Evaluate commonly practiced approaches to cavity filling using the water analog method of simulation	Indiana Contech (Mishawaka) Delaware Machinery (Muncie) General Motors Powertrain (Bedford) Matrix Technologies (Muncie)	General Die Casters (Peninsula) ITT Industries (Solon) Makino, Inc. (Mason) Sandvik Coromant (Cincinnati)
Deflection of Die Casting Dies: Prediction and Attentuation	•Control and prevention of die deflectors	Ryobi Die Casting (Shelbyville)  Michigan Carbolay, Inc. (Warren) CMI Tech Center, Inc. (Ferndale)	Pennsylvania Alcoa Technical Center (Alcoa Center)  Wisconsin J.L. French Corp. (Sheboygan)
Visualization Tools for Die Casting Part & Die Design	•Minimize solidification-related defects in the part; and minimize flow-related fill and thermal problems in casting.	Ford Motor Co. (Dearborn) GM Tech Center (Warren) Prince Machine, Co. (Holland) Minnesota	Walkington Engineering (Cottage Grove)  Ontario, Canada  EXCO Engineering (New Market)
Research Site: Ohio St Polytechnic Institute	ate University/Worcester	Tool Products (Minneapolis)  New York	Sweden Sero Tool AB Uddeholm Tooling
Study of Alloy Microstructure Performance Interaction	Gain an understanding of aluminum die casting alloys     Provide a database for die casting producers/designers	Crucible Materials Group (Camillus)	oddenom roomig
Research Site: Penn Si Missouri - Rolla	tate University/ University of	Illinois American Foundrymen's Society (Des Plaines) Steel Founders' Society of America (Des Plaines) Wells Manufacturing (Woodstock)	Ohio Buckeye Steel Casting Co. (Columbia) Flow Technology (Cincinnati)
Casting Dimensional Control and Fatigue Life Prediction for Permanent Mold Casting Dies	Improve casting tolerance tables for customers     Reduce overall cost of dimensional compliance	lowa Keokuk Steel Castings (Keokuk)	Oregon Varicast (Portland) Pennsylvania
mold dusting bles	•Expand market for steel castings	Maryland Universal Energy Systems (Annapolis)  Massachusetts	Pennsylvania Foundry & Machine (Hamburg)  Tennessee  American Magotteaux Intl, (Pulaski)
		Wollaston Alloys, Inc. (Braintree)  Michigan  CMI, International (Ferndale)	Texas Texas Foundries (Lutkin) Texas Steel Co. (Ft. Worth)
		Minnesota Progress Castings Group, Inc. (Plymouth)	Washington Spokane Industries (Spokane)
		Missouri Stahl Specialty Co. (Kingsville)	Wisconsin Falk Corp. (Milwaukee) Pelton Casteel (Milwaukee)
		New York Esco Corporation (Syracuse)	Ontario, Canada Foseco- Morval, Inc. (Kitchener)
	ity of Alabama - Birmingham	Alabama Alexander City Casting (Alexander City) Citation Corp. (Birmingham)	North Carolina Consolidated Diesel (Whitakers) Selee Corp. (Henderson)
Advanced Lost Foam Casting Technology	Establish acceptable ranges for production coatings     Reduce scrap     Improve casting quality     Remove or minimize oxide defects	Citation Foam (Birmingham) Mueller Corp. (Albertville) Vulcan Engineering Co. (Helena)  California AB&I (Oakland)	Ohio Ashland Chemical Co. (Dublin) Bradken Marion Corp. (Marion) Ductile Iron Society (North Olmstead) Eaton Corp. (Willoughby Hills) General Motors Corp. (Defiance)
Clean Cast Steel Technology	Reduce degradation of molds     Improve machinability     Eliminate inclusions	Georgia Tecpro Corp. (Atlanta)  Illinois Air Liquide (Countryside)	Kelsey-Hayes (Freemont) Sandvic, Inc. (Cincinnati) Sawbrook Steel Castings (Cincinnati) Willard Industries (Cincinnati)
Technology for the Production of Clean, Thin Wall Machinable Gray and Ductile Iron Castings	Reduce degradation of molds Improve machinability Eliminate inclusions	American Foundrymen's Society (Des Plaines) American Steel Foundries (Granite City) Austin Associates (Quincy) Caterpillar, Inc. (Peoria) General Kinematics Corp. (Barrington) Ingersoll Cutting Tool (Rockford) National Castings (Cicero) Precision Twist Drill (Crystal Lake) Taussig Associates (Skokie) Wells Mfg. (Woodstock)	Pennsylvania Advanced Cast Products (Meadville) J.S. McCormick (Pittsburgh) Premier Refractories & Chemicals (King of Prussia)  Tennessee American Magotteaux Intl. (Pulaski) Saturn Corp. (Spring Hill) Wheeland Foundry Co. (Chattanooga)  Texas
		Indiana Auburn Foundry, Inc. (Auburn) Cummins Engine Co. (Columbus) Electric Steel Castings Co. (Indianapolis) Harrison Steel Castings (Attica) The Maco Corporation (Huntington) Matrix Technologies (Muncie) Navistar I.C.C. (Indianapolis)	B&W Manufacturing (San Angelo) Styrochem Intl. (Ft. Worth) Texas Steel Co. (Ft. Worth)  Wisconsin Arneson Foundry Inc. (Kenosha) Borden, Inc. (Oak Creek) Briggs & Stratton (West Allies) FALK Corporation (Milwaukee)
		Iowa Keokuk Steel Castings, Inc. (Keokuk)  Kansas Atchison Casting Corp. (Atchison)  Maryland UES Inc. (Annapolis)	Kohler Co. (Kohler) Lost Foam Tech. Inc. (Sheboygan Falls) Maynard Steel Castings Co. (Milwaukee) Mercury Marine (Fond Du Lac) Stainless Foundry & Engineering (Milwaukee) Waupaca Foundry (Waupaca) Wisconsin Centrifugal, Inc. (Waukesha)
		Michigan Ancast, Inc. (Sodue) Ford Motor Co. (Dearborn) General Motors Corp. (Warren) Simpson Industries (Jackson)	Ontario, Canada Bowmanville Foundry Co. (Bowmanville) Dominion Castings Ltd. (Hamilton) Foseco-Morval Inc. (Kitchener) United Kingdom Stanton PLC

Research Site: University Florida A&M The Relationship between Casting Distortion, Mold Filling, and Interfacial Heat Transfer in Sand Molds Research Site: University Wear Analysis of Foundry Tooling Materials	materials and operations	Illinois American Foundrymen's Society (Des Plaines)  Illinois Caterpillar (East Peoria) Clinkerbeard & Associates (Rockford) Wagner Castings Co. (Decatur) Iowa Bloomfield Foundry, Inc. (Bloomfield) Michigan	Tennessee Wheland Foundry (Chattanooga) Wisconsin Brillion Iron Works (Brillion) Casting Design & Service (Two Rivers) Finn Pattern Co. (Cudahy) Neenah Foundry Co. (Neenan)	
B		CMI International (Ferndale) Grede Foundry (Kingsford)  Missouri St. Louis Precision Casting Co. (St. Louis)	Reedsburg Foundry (Reedsburg) Waupaca Foundry (Waupaca)  Texas	
Research Site: Univer	sity of Tennessee	Alabama Southern Alloy (Sylacauga)	KO Steel (San Antonio)	
Microstructural Evaluation of High Alloy Stainless and Nickel Base Castings	Define the microstructural characteristics of the cast high alloy materials in terms of heat treatment and welding	lowa Keokuk Steel Casting (Keokuk)  Massachusetts Wollaston Alloys (Braintree)  Pennsylvania Quaker Steel Castings (Reading)	Washington Atlas Foundry & Machine (Tacoma)  Wisconsin Stainless Foundry (Milwaukee) Waukesha Fluid Hardening (Waukesha) Waukesha Foundry (Waukesha) Wisconsin Centrifugal (Waukesha)	
Research Site: Univer Development of Lead-Free Copper Alloy-Graphite Castings	*Allow production of lead-free plumbing fixtures, bearings, and other engineering components.	Illinois Accurate Castings (Addison) Aurora Industries (Montgomery) Superior Graphite (Chicago) Indiana Federal Mogul (Mooresville) Michigan Glacier-Clevite (Ann Arbor) Grand Haven Brass Foundry (Grand Haven)	Ohio ANI Metals (Marion) Bunting Bearings Corp. (Mansfield)  Pennsylvania Colonial Metals (Columbia)  Wisconsin Johnson Controls Foundry (Milwaukee) Kohler Co. (Kohler) Outboard Marine Corp. (Waukesha) Starline Industries (Milwaukee)	
Research Site: Worcestire Polytechnic Institute		Massachusetts	North Carolina	
Clean Metal Processing (Aluminum)	•Develop methods for metal cleanliness assessment and melt contaminations avoidance, and augment fundamental knowledge base	Kennedy Die Casting Inc. (Worcester)  Minnesota Hitchcock Industries (Minneapolis)  Missouri Stahl Specialty Corp. (Kingsville)	Selee Corp. (Hendersonville)  Ohio Foseco Inc. (Cleveland)  Wisconsin Madison - Kipp Corp. (Madison)	

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